Radiation tolerance of MT multi-way single mode fibre-optic connectors to gamma and neutron irradiation

J. Batten[1], K. Gill[2], J. Troska[1], F. Vasey[2]

1) High Energy Physics Group, Imperial College, London SW7 2BZ, UK

2) CERN, CH-1211, Geneve 23, Switzerland.

Abstract

Single mode optical links are being developed to transfer analogue tracking data and digital timing and control signals in the proposed Compact Muon Solenoid experiment (CMS) at CERN's Large Hadron Collider (LHC). The radiation environment inside the CMS tracker will be extreme, with hadron fluences up to ~10^{14}/cm^2 and ionising doses of ~100kGy. The high number of optical channels (~50,000) and strict limit on available space for connectors demands a compact multi-way fibre-optic connector. The MT connector has been selected as a candidate, and tested for radiation hardness up to the doses expected at the LHC, by measuring the insertion loss over repeat matings following gamma and neutron irradiation. Visual inspection of the connector ferrules revealed no degradation or damage due to irradiation, and insertion loss is unaffected with typical values of 0.24dB and standard deviations of 0.15dB. Multiple remate tests were performed and no degradation due to irradiation was observed. The connectors are found to be suitable to form the basis of optical connection in the CMS experiment.

I. INTRODUCTION

Particle physics experiments currently being designed to study very high energy proton-proton collisions at the Large Hadron Collider (LHC)[1] at CERN, Switzerland, will make extensive use of fibre optic readout for their particle detectors. In the Compact Muon Solenoid (CMS)[2] the central part of the detector, the tracker, consists of 14 million electronic channels, which will be multiplexed and read out at 40MSamples/s via a 100m long single mode optical link consisting of ~50,000 optical channels[3]. The deployment of an optical fibre link in the experimental environment is very challenging particularly with respect to the radiation levels which will be encountered. The total ionising dose is expected[4] to be 10Mrad over the nominal ten-year lifetime of the experiment. Over the same period a hadron fluence equivalent to ~10^{14} /cm^2 is expected.

One aspect of the viability of such an optical link is the availability of suitable radiation tolerant optical connectors. In addition to being radiation tolerant these must be both compact and of low mass, as the volume and density of material allowed for optical and electrical connectors is strictly limited in order to maintain the performance of the CMS detector.

The presence of a very high number of optical channels suggests a hierarchy of channel grouping to facilitate fibre management, and at the lowest level ribbons of 4, 8 or 12 fibres are envisaged. Three break points must be incorporated into the link to enable assembly and maintenance of the detector, and for connection to readout modules. The multi-way MT connector [5,6] has been selected as a candidate for this application due to its high modularity, compact size and its compatibility with ribbon fibres. A schematic of the connector is shown in figure 1. Up to 12 fibres can be accommodated in a ferrule measuring 7mm wide, by 3mm high, by 8mm long. Two stainless steel guide pins align the fibres to the necessary sub-micron precision. Ferrules are moulded in fused silica-epoxy composite, and manufactured in plants in the U.S.A. and Japan. The MT has been utilised in multi-fibre data and telecommunication links, most notably in Japan, but not in a high radiation environment: this study is relevant to the application of multi-way optical links in high radiation environments outside of high energy physics where a compact connector is required.

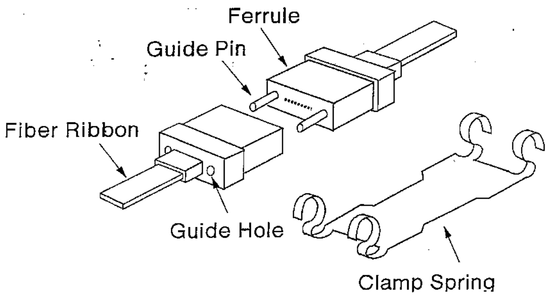


Figure 1: Schematic of the MT connector, showing ferrule, guide pin and clamp spring.

The principle concern before the tests were made, was that the radiation levels would affect either the material of the MT ferrule itself or the bond between the fibre and ferrule, leading to axial movement of the fibre. Movement of a few tens of microns leads to significant increase in the insertion loss of the connector. Cracking or chipping of the ferrule could lead to large insertion losses or complete failure. The primary goals of the tests were to show that the connector did not undergo any catastrophic failure, and having done this to assess the level of degradation due to irradiation if present.

Presented at RADECS 97 Conference, Cannes, Sept. 1997

II. SAMPLES AND IRRADIATIONS

Twelve patch cords utilizing standard single mode telecommunication fibre ribbon of 1.2m in length were used in the tests. Termination was with angle polished MT8-S connectors yielding a sample of 24 connectors available for testing. Four groups were formed with three patch cords in each group for irradiation with a combination of gamma rays and neutrons. The ^{60}Co source at Imperial College provided the gamma rays; neutron irradiation ($<E_n>$~6MeV) was carried out at the SARA facility[7] in Grenoble. The total doses, dose rates, neutron fluence and neutron flux are shown in table 1. Gamma dose rates were measured with a silicon diode with an accuracy of ~10% while the neutron fluence was measured with Ni foil dosimeters with an accuracy of ~15%.

Table 1.
Irradiation details of the four groups of connectors.

Group	gamma dose	gamma dose rate	neutron fluence	neutron flux
A	190 kGy	2.2 kGy/hr	$7.7\text{x}10^{13}$ N/cm^2	$6\text{x}10^{11}$ N/cm^2/hr
B	none		$7.7\text{x}10^{13}$ N/cm^2	$6\text{x}10^{11}$ N/cm^2/hr
C	190 kGy	2.2 kGy/hr	none	
D	control		control	

The ^{60}Co source is distributed within 4 source rods. The connectors were taped together and centred between two of the rods, the axes of which were separated by 78mm. Variation in the dose across the bundle of connectors, which measured 20mm wide along the axis between the rods, was estimated to be ~7%. The coiled ribbon fibre received ~40% of thedose recieved by the connectors.

Neutrons from SARA form a conical beam with 30° width at half intensity and guassian shaped profile. At a distance of 30cm from the beam source the MT ferrules subtended an angle of ~4° leading to a low variation of only a few percent in the fluence received by the samples. The coiled ribbons received ~30% of the fluence received by the MT's.

III. TEST PROCEDURE

All the samples were manufactured by Europtics Ltd[8]. Initial measurements of insertion loss were made immediately following manufacture. Neutron and gamma irradiations were carried out within a month of manufacture. The re-tests were carried out four months after manufacture. The schedule is summarised in table 2.

All insertion loss measurements were made at 1310 nm using a stabilised light source and wide area InGaAs detector. A diagram of the set-up is shown in figure 2. A single launch lead was used throughout the tests, made from the same batch of ribbon fibre that was used for the patch cords. Mating of connectors was effected using the clamp spring, attached from alternate sides for each mating. The end surface of the ferrules were cleaned prior to measuring.

Table 2.
Manufacture , irradiation and test schedule.

	Manufacture and initial test	Neutron irradiation	Gamma irradiation	Re-test
Week	0-1	1-2	3-4	17

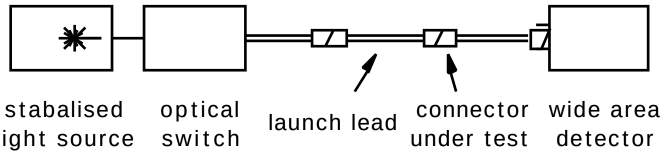


Figure 2: Diagram of the insertion loss measurement set-up.

IV. RESULTS

A. Insertion loss measurements

For each fibre in each connector one reference measurement and five insertion loss measurements were taken. Figure 3 shows the results for group A which was exposed to both gamma and neutron radiation. The mean of the 48 connector channels is 0.18 dB for the 1st test and 0.21 dB for the 2nd test. Given the spread of values this rise is not significant. A histogram of the insertion loss for group A and groups B to D is shown in figure 4. The mean and rms deviations for each group are given in table 3 below. These show similar values, although the 2nd test on the control sample shows a marked rise in the insertion loss. This unexpected result is discussed in section V.

Table 3.
Insertion loss mean and rms deviation from five measurements.

	1st test Insertion loss (dB)		2nd test Insertion loss (dB)	
Group	mean	rms dev.	mean	rms dev.
A	0.18	0.12	0.21	0.14
B	0.24	0.18	0.24	0.16
C	0.24	0.15	0.23	0.18
D	0.10	0.08	0.27	0.20

B. Repetitive re-mate tests

Two patch cords — one from group A which had been irradiated with gammas and neutrons, and one from the control group D — were tested again, mating and re-mating the connector 100 times. The ferrule ends were cleaned after 10 re-mates and the insertion loss was measured every 5 re-mates. Similarly, 40 re-mate measurements were carried out as part of the initial test. The data are shown in figure 5.

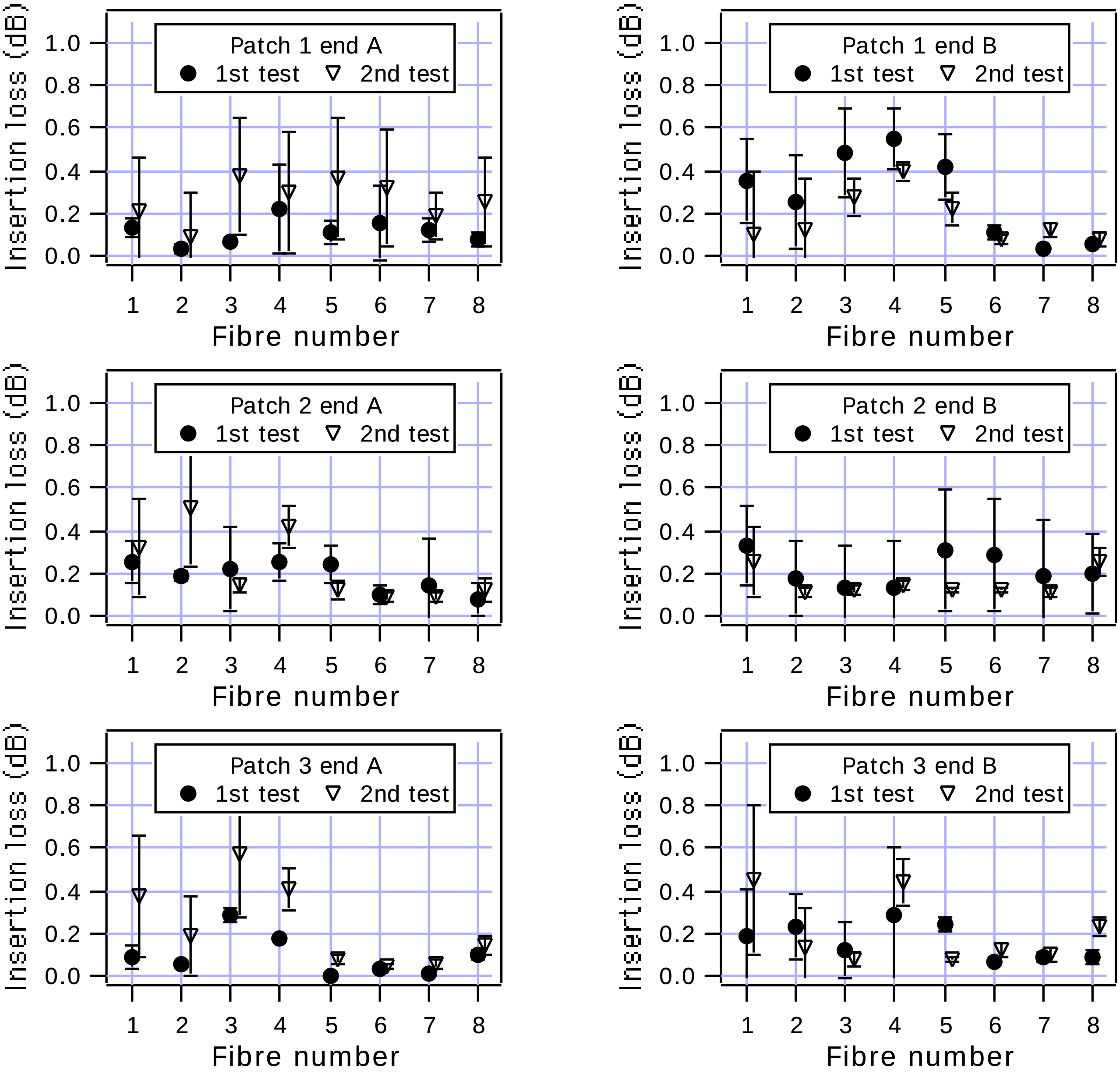


Figure 3: Insertion loss of connectors in group A before (1st test) and after (2nd test) gamma and neutron irradiation. The data show a high level of consistency with variations across the connectors repeated in the re-test,.despite a 4 month interval between measurements. The error bars are rms deviations of the five measurements on each connector, providing an indication of the repeatibility of connector performance.

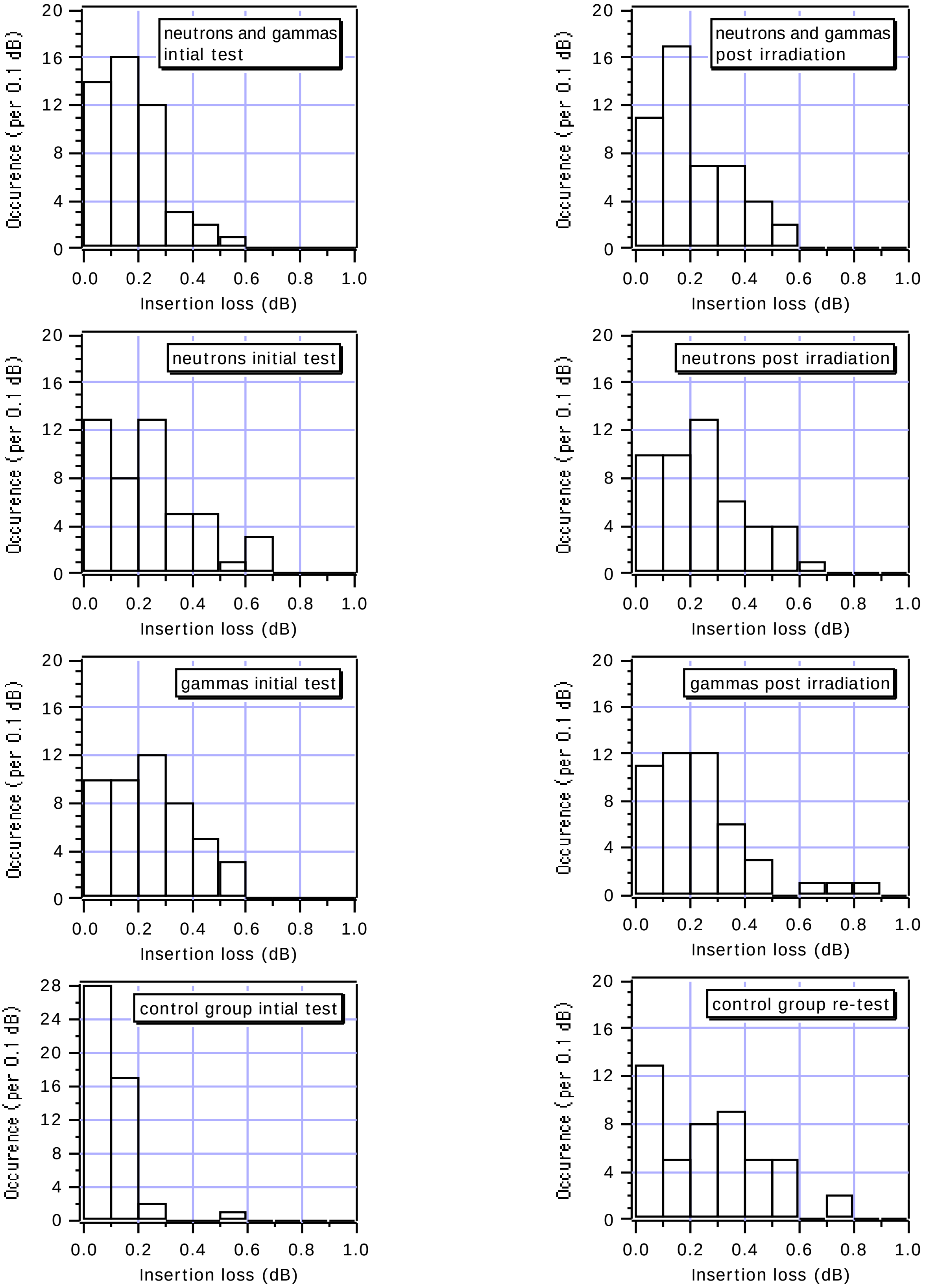


Figure 4: Histograms of insertion loss before (initial test) and after (post) irradiation for each group showing negligible increase in insertion loss. The bottom two histograms are for the control sample: this group had particularly good performance for the initial test, but three connectors suffered from guide pin damage during the re-test leading to the observed rise in insertion loss.

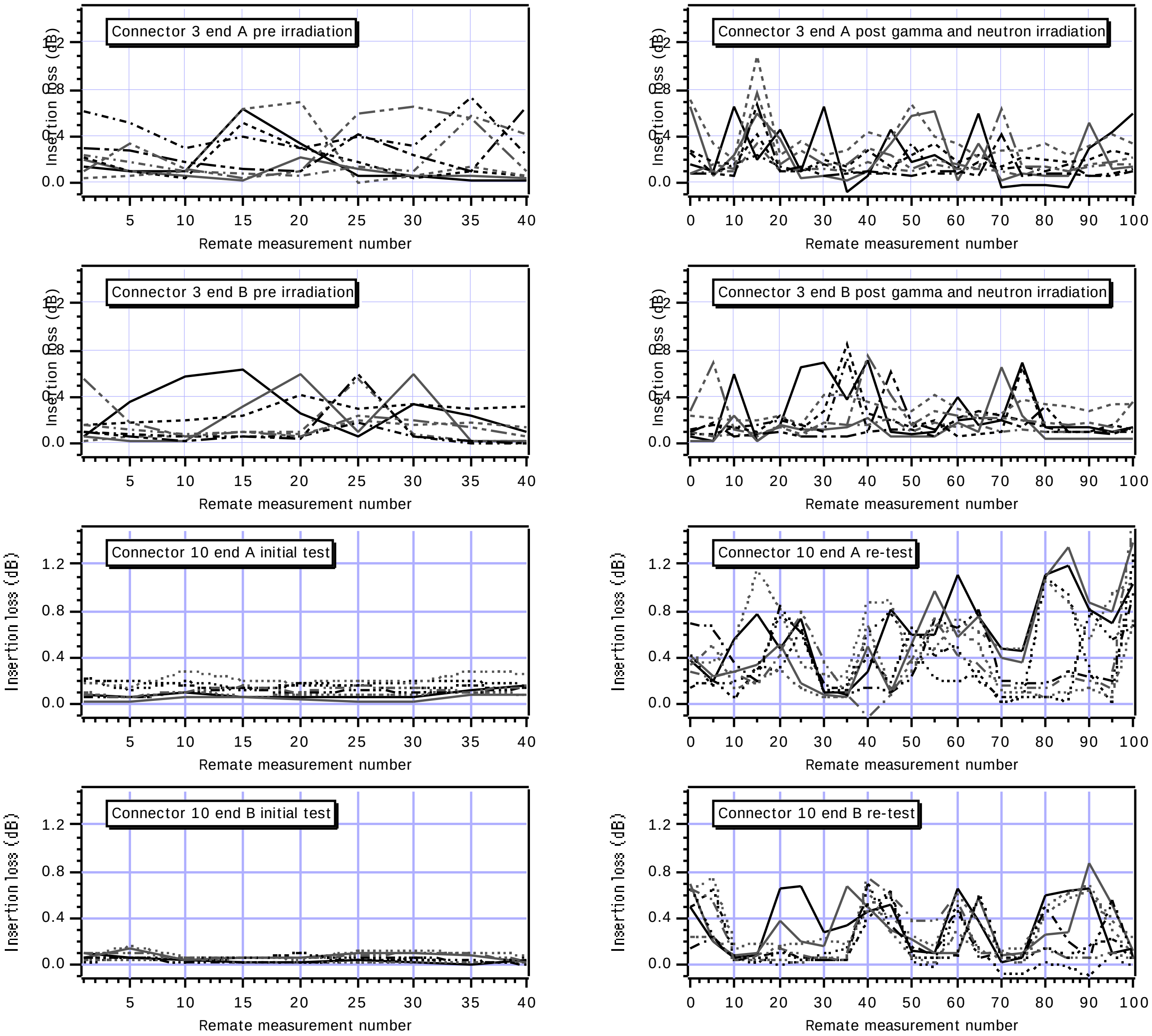
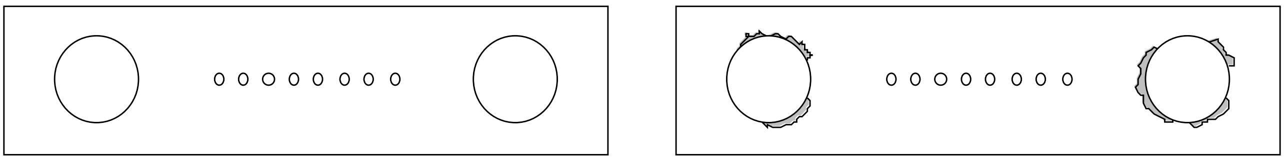


Figure 5: Repetitive re-mate measurements 1st and 2nd tests: connector 3, before and after gamma and neutron radiation; connector 10 (control group) initial test and re-test. Connector 3 shows no increase in variation over repeat re-mates following irradiation. Connector 10, one of the control connectors, shows a marked increase in the level and variation of insertion loss. This was traced to damaged guide pine holes caused at the start of the 2nd test.



pristine MT connector endface

MT with damaged guide pins

Figure 6: Schematic of the damaged guide pin holes to which the poor re-test performance of the control group was attributed.

V. DISCUSSION

A. Insertion loss measurements

The mean insertion losses of each group as given in table 2 indicate no degradation in the performance of the connectors due to irradiation. A small increase in attenuation due to darkening of the optical fibres might have been expected, however 0.1 dB/m is a typical loss for germanium doped single mode fibre at a dose of 80 kGy[9]. Radiation induced absorption anneals, however, and the attenuation present when the patch cords were tested 10 weeks after the irradiation would be expected to be negligible. The attenuation due to the neutron fluence (~2x10^{13}N/cm^2) would also be insignificant[9].

The poor performance of the control group in the re-test is accentuated by the fact that the group had, by chance, particularly good performance initially. The increase in attenuation was observed in three connectors which were found to have chips around the guide pin holes. This is illustrated schematically in figure 6. These connectors were the first to be tested and it is likely that the guide pins had some contamination which affected only the start of the test. This is an important issue for use of the MT in the CMS experiment and indicates the need for the adoption of strict and controlled connection procedures if the full performance of the MT is to be realised. Even with the damaged guide pin holes, however, the performance of the connector was better than 1.2 dB — within the performance specification of the MT. The very low insertion loss values obtained demonstrates the very high performance possible with these connectors.

B Relevance of the results to CMS

The total attenuation load for the three break points needed in the tracker optical link is close to 2 dB[10]. Matrix connectors based on the MT ferrule are the baseline choice for the tracker optical link: this figure is consistent with the insertion loss measurements presented here. Areas which will be investigated further are the effect of mechanical stress on the fibre ribbon exiting the ferrule and the effect on performance of the MT in a random mate test — one using a launch lead incorporating ribbon fibre from a different production run to that used for the patch cords. Random mate measurements could be expected to give higher insertion losses of the order 0.2-0.3 dB.

VI. SUMMARY

Extensive insertion loss measurements have been made using MT8-S connectors exposed to gamma and neutron radiation levels expected in LHC experiments. Insertion losses in the region of 0.25 dB and rms deviations typically of 0.17dB have been measured. No catastrophic degradation of the ferrule occurred due to radiation effects even with repetitive remate tests. Poorer performance of the control group in the 2nd test, reaching the maximum specified MT loss of 1.2 dB, was thought to be caused by chipping around the guide pin holes, illustrating the need for a high level of cleanliness during connection.

The MT connector is the baseline choice for the CMS tracker optical link which incorporates 50,000 optical channels. The performance of the connector is not significantly affected by the radiation levels expected within the LHC detectors, allowing system designs to be based on MT derived connectors.

VII. ACKNOWLEDGEMENTS

The authors wish to thank Philippe Martin for help with the neutron dosimetry, and Peter Clay for help with the gamma irradiations. Insertion loss measurements were performed at Europtics: we thank Martin Davies for organising the tests and for many useful discussions.

VIII. REFERENCES

[1] The LHC Conceptual Design Report — The Yellow Book, CERN/AC/95-05(LHC), 1995, CERN, CH-1211.

[2] The Compact Muon Solenoid Technical Proposal. CERN Report LHCC 94—38, 1994, CERN, CH-1211.

[3] G.Hall, G. Stefanini and F. Vasey, "Fibre optic link technology for the CMS tracker," CMS NOTE/96—012, 1996, CERN, CH-1211.

[4] M.Huhtinen, "Radiation Environment Simulations for the CMS Detector," CMS TN/95—198, 1995, CERN. CH-1211.

[5] T. Satake, S. Nagasawa and R. Arioka, "A new type of demountable plastic-molded single-mode multifiber connector," *J. Lightwave Technology*, vol. LT-4, no 8 pp.1232–1236, 1986.

[6] T. Satake, N. Kashima, and M. Oki, "Very small single-mode ten-fiber connector," *J. Lightwave Technology*, vol. 6, no 2 pp.269–272, 1988.

[7] J.Collot et al., "A neutron irradiation facility featuring cryogenic temperatures and dedicated to Large Hadron Collider detector design," *Nucl. Instr. Meth. A*, 350, p.525, 1994.

[8] MT terminated patch cords, manufactured by Europtics Ltd, Helsby Technology Centre, Chester Road, Helsby, Cheshire, WA6 0DJ, England, UK.

[9] K. Gill, R. Grabbit, M. Persello, G. Stefanini, F. Vasey, "Gamma and neutron radiation damage studies of optical fibres," *J. Non-Cryst. Sollids,* (in print).

[10] "Optoelectronic Analogue Signal Transfer for LHC Detectors", RD23 Collaboration Status Report, CERN/LHCC 97-30 (1997). For more information see the RD23 www page: http://www.cern.ch/RD23/.